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ALTITUDE PERFORMANCE OF ANNULAR COMBUSTOR TYPE

TURBOJET ENGINE WITH JFC-2 FUEL

By James W. Useller, James L. Harp, Jr., and Zelmar Barson

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ERRATA

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- Page 1, line 3: Change "diesel" to "kerosene."
- Page 1, line 17-18: Change "diesel fuel" to "140° F flash kerosene."
- Page 3, line 12: Change "diesel fuel" to "140° F flash kerosene."
- Abstract, line 4: Change "diesel fuel" to "140° F flash kerosene."

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RESEARCH MEMORANDUM

ALTITUDE PERFORMANCE OF ANNULAR COMBUSTOR TYPE TURBOJET

ENGINE WITH JFC-2 FUEL

By James W. Useller, James L. Harp, Jr.
and Zelmar Barson

SUMMARY

An investigation was made comparing the performance of JFC-2 fuel and unleaded clear gasoline in a 3000-pound-thrust turbojet engine. The JFC-2 fuel was a blend of 75 percent diesel type fuel and 25 percent aviation gasoline. The two fuels performed equally well at rated engine speed at altitudes up to 35,000 feet, but combustion efficiency with the JFC-2 fuel was lower both at reduced engine speeds and at higher altitudes. Turbine-discharge radial temperature profiles for the two fuels were comparable except at an altitude of 45,000 feet, where the JFC-2 fuel gave a flatter profile than gasoline. At the flight Mach number simulated, low-speed combustion blow-out of the engine was not encountered with either fuel at tail-pipe temperatures above 150° F. Several normal low-altitude engine starts showed no apparent difference in the starting characteristics of the two fuels. *see errata*

INTRODUCTION

The problem of providing adequate protected bunker space for high-volatility fuel on board aircraft carriers has led to an attempt to find a satisfactory turbojet engine fuel that could be stored in unprotected bunkers aboard fleet aircraft carriers. A blend of 75 percent diesel fuel and 25 percent aviation gasoline was proposed for this use by the Bureau of Aeronautics, Department of the Navy. This turbojet engine fuel blend was designated JFC-2 fuel. In carrier use, such a fuel would be blended as needed, thus requiring only 25 percent of the protected bunker space now required. An obvious improvement in effective utilization of the jet aircraft aboard carriers would result. *see errata*

As a part of the general study of the JFC-2 fuel being directed by the Bureau of Aeronautics, the performance of a 3000-pound-thrust turbojet engine using this blend was investigated in an NACA Lewis laboratory altitude test chamber. The investigation included a comparison of the engine performance using JFC-2 fuel and using a clear unleaded gasoline.

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The engine performance was obtained for a range of engine speeds at simulated altitudes from 10,000 to 45,000 feet at a flight Mach number of 0.8. The low-engine-speed blow-out limit was investigated at each altitude, and low-altitude engine starts were performed. The turbine-discharge gas-temperature gradients and the carbon-deposition characteristics of the JFC-2 fuel were observed.

APPARATUS

Engine

The investigation was conducted on a J34-WE-22 turbojet engine having a thrust rating of 3000 pounds at an engine speed of 12,500 rpm at sea level with zero ram. The engine components (fig. 1) included an 11-stage axial-flow compressor, a compressor discharge mixer, a double annular combustor of the through-flow type, a two-stage axial-flow turbine, and a variable-area exhaust nozzle. The compressor-discharge mixer (fig. 2) was employed to produce a more favorable compressor discharge velocity gradient and consequently an improved turbine radial temperature distribution. The action of the mixer on the compressor-discharge air flow was such that in alternate vanes the air at the tips of the compressor blades was forced inward and the air at the blade roots followed an outward path resulting in turbulent mixing of the air flow entering the combustor. The standard engine fuel system was used throughout the investigation.

Altitude Test Chamber

The engine was installed in an altitude test chamber (fig. 3) which was 10 feet in diameter and 60 feet long, and included air-straightening vanes, front and rear bulkheads, and an exhaust diffuser. The engine was mounted on a thrust stand which was connected to a thrust-measuring cell through a series of linkages. The engine inlet extended through the front bulkhead and freedom of movement was provided by means of a labyrinth seal. A rear bulkhead was installed around the engine tail pipe to prevent recirculation of the hot exhaust gases around the engine. It was possible to observe upstream through the exhaust nozzle and turbine into the combustion chamber during engine operation by means of a periscope installed in the downstream section of the test chamber.

Instrumentation

Air flow, fuel flow, engine speed, and temperatures and pressures were measured at various stations in the engine and test chamber. The manufacturer of the J34 turbojet engine has recommended the maintenance

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of a specified radial gas temperature profile across the turbine-discharge annulus (based on blade stress considerations) as good operating practice. Particular attention was given to the measurement of the radial gas temperature distribution at this position in the engine to conform to this specification. The instrumentation for the measurement of the turbine-discharge gas temperature consisted of six rakes each with eight stagnation-type chromel-alumel thermocouples. The thermocouple spacing on the rakes was arranged so as to represent equal flow areas, and the thermocouples were located in a plane $2\frac{3}{4}$ inches downstream of the turbine.

Fuels

The fuels used were unleaded, clear gasoline and JFC-2 fuel. The JFC-2 fuel is a blend of 75 percent ~~diesel fuel~~ and 25 percent grade 115/145 aviation gasoline (MIL-F-5572) by volume. A fuel analysis for each fuel is presented in table I. *see errata*

PROCEDURE

The altitude performance of the engine with both gasoline and JFC-2 fuel was investigated at a flight Mach number of 0.8 at simulated altitudes of 10,000, 35,000, and 45,000 feet. At each flight condition, performance was determined for a range of engine speeds from 84 percent to 100 percent rated speed (12,500 rpm), with the variable-area exhaust nozzle set to obtain a limiting tail-pipe gas temperature at rated speed. The limit was considered to have been reached as soon as any one point on the turbine-discharge gas temperature profile coincided with the limiting temperature profile specified by the manufacturer for 100 percent rated engine speed. The standard starting procedure used during this investigation consisted in windmilling the engine to a speed of approximately 10 percent of rated speed (flight Mach number of approximately 0.2) at an altitude between 5000 and 15,000 feet before attempting ignition.

Inlet and exhaust pressures were set to correspond to the desired flight conditions conforming to NACA standard atmosphere and assuming 100-percent ram recovery. The altitude pressures were set to within ± 0.02 inch of mercury and, in general, the inlet temperature was set to within $\pm 5^\circ$ F. The error in measurement of the primary variables, pressure, temperature, engine speed, and fuel flow, was considered to be not greater than ± 2 percent. The data presented have been adjusted to NACA standard pressures and temperatures for the flight conditions investigated.

RESULTS AND DISCUSSION

Combustor Performance

In the comparison of turbojet engine fuels, primary consideration should be given to the combustion efficiencies obtained with each fuel when the engine is operating under similar conditions. Combustion efficiency was calculated in this investigation as the ratio of the enthalpy rise of the gas across the combustor to the heat input (reference 1). The engine performance with JFC-2 fuel was compared with that obtained with unleaded, clear gasoline which is normally used in the J34 turbojet engine.

The effect of engine speed on combustion efficiency of the JFC-2 fuel and gasoline at several altitudes is shown in figure 4. At an altitude of 10,000 feet, the engine combustion efficiency during operation with the JFC-2 fuel was less than with gasoline at engine speeds from 80 to 90 percent rated speed, although the combustion efficiency with the JFC-2 fuel became equal to that with gasoline at rated engine speed. When the altitude was increased to 35,000 feet, the divergence between the combustion efficiencies at low engine speeds became greater than at the lower altitude, but the efficiency with JFC-2 fuel remained equal to gasoline at rated engine speed. At an altitude of 45,000 feet, where combustion is more difficult, the combustion efficiency with gasoline was 92 percent at rated speed, while the efficiency with the JFC-2 fuel reached only 86 percent at this speed.

Carbon Deposition

After 6 hours and 35 minutes of engine operation at various simulated flight conditions with JFC-2 fuel, the combustion chamber was disassembled and inspected for carbon deposition and warping. Globular carbon formations were present in the upstream end of the combustor liner at random locations (fig. 5). A total of 34.4 grams of carbon was deposited in the combustion chamber; however, the engine fuel nozzles and spark plugs were free from carbon formations.

The carbon-forming tendencies of fuels depend on the combustor design, the operating conditions, the burning time, and the physical and chemical properties of the fuel. A decrease in carbon deposition rate can be anticipated with operation at increased altitudes because of the decreased fuel flow and for other reasons that are explained in detail in reference 2. The rate of carbon formation determined is therefore comparable only at flight conditions similar to those reported herein. Carbon deposition with gasoline was not evaluated during this investigation because previous investigations have reported it to be extremely small or completely absent. The carbon deposition with JFC-2 fuel was

much less severe than with MIL-F-5624 (AN-F-58) type fuels used in a similar engine as reported in reference 3, where 240 grams of carbon were deposited during approximately 30 hours of operation. No serious warping or other deterioration of the combustor components was observed after operation with the JFC-2 fuel.

Engine Performance

The radial gas temperature distribution at the turbine discharge for each of the altitudes investigated with the engine operating at rated speed is shown in figure 6. The two fuels are compared and the temperature limit specified by the manufacturer has been superimposed. The average operating turbine-discharge gas temperature was established by adjustment of the variable-area exhaust nozzle to maintain the temperature profile within the manufacturer's specified limit. The turbine-discharge gas temperature profiles for both fuels at rated engine speed were comparable at altitudes of 10,000 and 35,000 feet as shown in figures 6(a) and 6(b). At an altitude of 45,000 feet, operation with JFC-2 fuel produced a comparatively flat temperature profile across the turbine annulus (fig. 6(c)). The higher temperature achieved with gasoline at the center of the turbine blades was balanced by lower temperatures in the region of the roots and tips of the blades, producing approximately the same average turbine-discharge gas temperature.

Net thrust is presented as a function of percent rated engine speed for altitudes of 10,000, 35,000, and 45,000 feet in figure 7. Thrust was obtained at each altitude during operation with JFC-2 fuel equal to that obtained during standard engine operation with gasoline.

Engine fuel consumption as a function of percent rated engine speed for each altitude investigated is presented in figure 8. At low altitudes and 100 percent rated engine speed, the engine fuel consumption of JFC-2 fuel was approximately equal to that of gasoline. After an increase in altitude to 45,000 feet, the JFC-2 fuel consumption was approximately 9 percent above that of gasoline at rated engine speed.

Operational Characteristics

During low-altitude operation of the engine with gasoline, the flame in the engine combustion chamber was normally visible through the periscope. When JFC-2 fuel was used, the flame intensity was observed to increase somewhat. Flame continued to be visible in the combustion chamber until an altitude between 30,000 and 35,000 feet was reached. At higher altitudes the visible flame luminosity decreased so as to be invisible with both gasoline and JFC-2 fuel.

Low-engine-speed blow-out tests of the engine were made at a flight Mach number of 0.8 at altitudes of 10,000, 35,000, and 45,000 feet. The minimum-speed combustion blow-out limit was not encountered at any of these flight conditions during operation at tail-pipe gas temperatures in excess of 150° F.

Satisfactory low-altitude starts were accomplished at a flight Mach number of approximately 0.2 at altitudes between 5000 and 15,000 feet. The same starting technique was used with JFC-2 fuel as with gasoline. No discernible differences in starting characteristics of the engine were observed between the two fuels for the flight conditions investigated.

SUMMARY OF RESULTS

The following results were obtained in the comparison of the performance of JFC-2 fuel and gasoline in a 3000-pound-thrust turbojet engine operating at a flight Mach number of 0.8 at altitudes of 10,000, 35,000, and 45,000 feet:

1. For operation near rated speed at the low and intermediate altitudes, the combustion efficiencies and engine fuel consumptions with gasoline and JFC-2 fuel were approximately equal. At an altitude of 45,000 feet the JFC-2 fuel consumption was approximately 9 percent higher, and the combustion efficiency was similarly lower with JFC-2 fuel than with gasoline.

2. Equal thrust was obtained at each altitude operation with JFC-2 fuel as during standard engine operation with gasoline.

3. The turbine-discharge gas temperature profiles for both gasoline and JFC-2 fuel were comparable at altitudes of 10,000 and 35,000 feet. At an altitude of 45,000 feet, the JFC-2 fuel produced a more uniform temperature distribution from root to tip of the turbine blades than did gasoline at approximately the same average gas temperature.

4. During 6 hours and 35 minutes of operation at simulated flight conditions with JFC-2 fuel, a total of 34.4 grams of carbon was deposited in the combustion chamber.

5. Low-speed combustion blow-out was not encountered with either fuel at any of the flight conditions investigated during operation at tail-pipe gas temperatures in excess of 150° F.

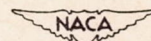
6. Several satisfactory low-altitude starts were accomplished at altitudes between 5000 and 15,000 feet and no discernible difference in starting characteristics was observed between the JFC-2 fuel and gasoline.

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National Advisory Committee for Aeronautics
Cleveland, Ohio

REFERENCES

1. Turner, L. Richard, and Lord, Albert M.: Thermodynamic Charts for the Computation of Combustion and Mixture Temperatures at Constant Pressure. NACA TN 1086, 1946.
2. Gibbons, Louis C.: Factors in Selecting Fuels for Gas-Turbine Powered Aircraft. NACA RM E50118, 1950.
3. Dowman, Harry W., and Younger, George G.: Comparison of Performance of AN-F-58 Fuel and Gasoline in J34-WE-22 Turbojet Engine. NACA RM E8L10a, 1949.

TABLE I. - ANALYSIS OF FUELS



	Unleaded, clear gasoline	JFC-2 fuel
A.S.T.M. distillation, (°F)		
Initial boiling point	102	142
Percentage evaporated		
5	127	192
10	143	230
20	164	289
30	184	338
40	204	371
50	222	394
60	239	407
70	250	420
80	274	436
90	301	457
95	322	471
Final boiling point	373	499
Residue (percent)	0.9	1.1
Loss (percent)	1.1	1.0
Freezing point (°F)	---	-60
Aromatics (percent by volume)	---	13.5
Bromine number	---	0.5
Reid vapor pressure (lb/sq in.)	7.0	2.0
Hydrogen-carbon ratio	0.180	0.164
Heat of combustion (Btu/lb)	18920	18667
Specific gravity	0.714	0.785
Aniline point (°F)	140.2	142.2

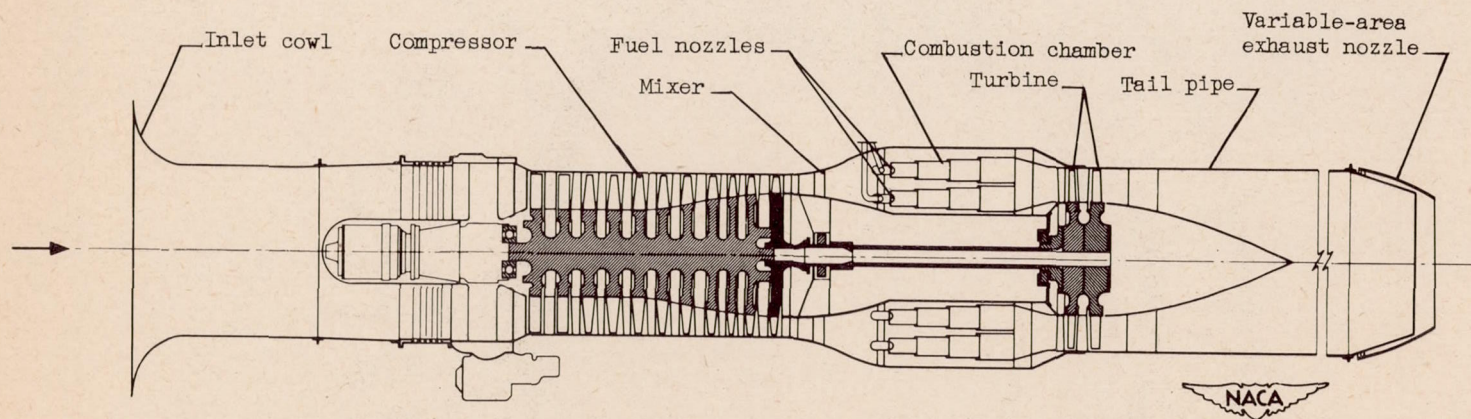


Figure 1. - Sectional view of J34-WE-22 turbojet engine.

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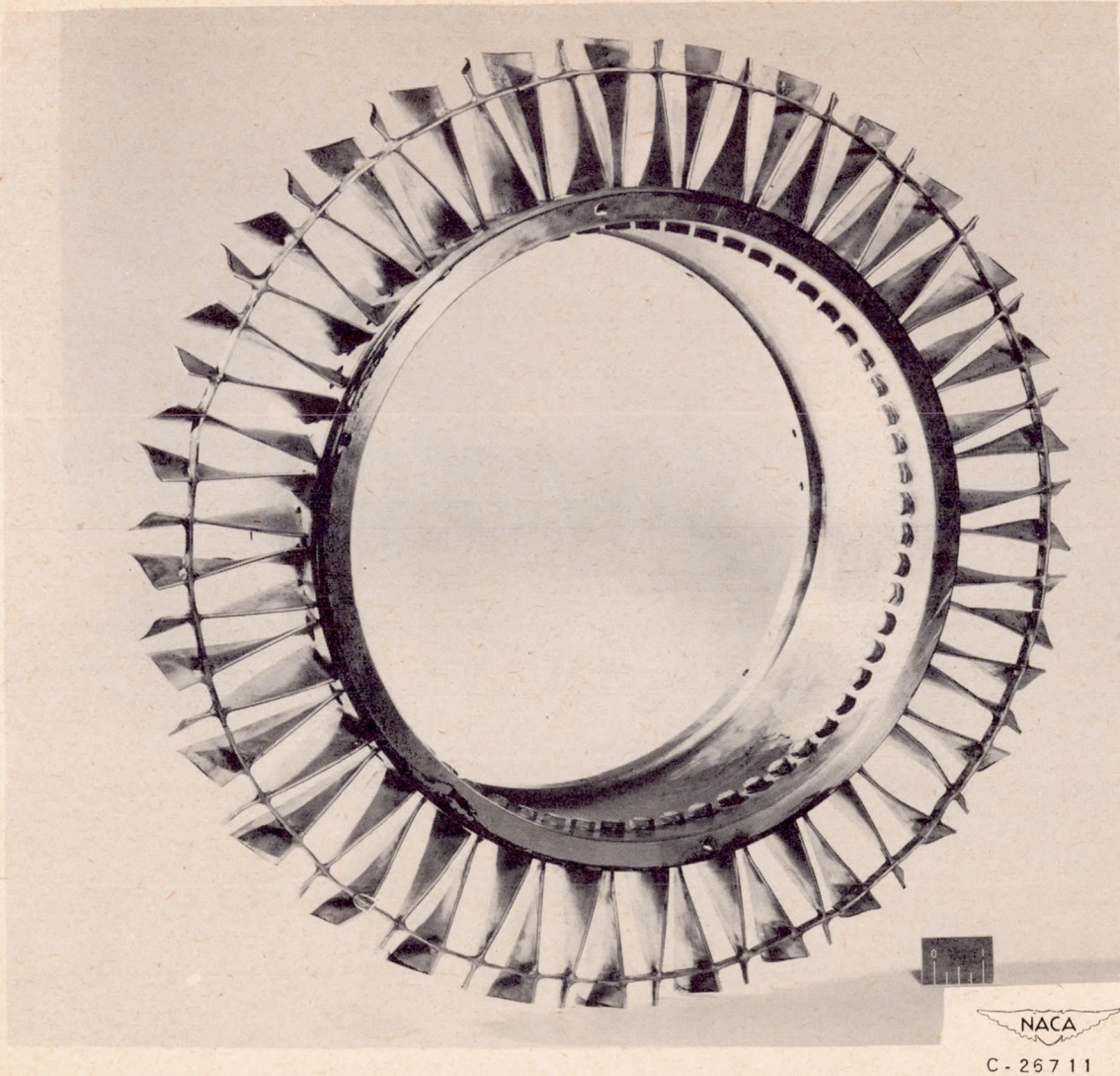


Figure 2. - Photograph of J34-WE-22 turbojet engine compressor discharge mixer assembly.

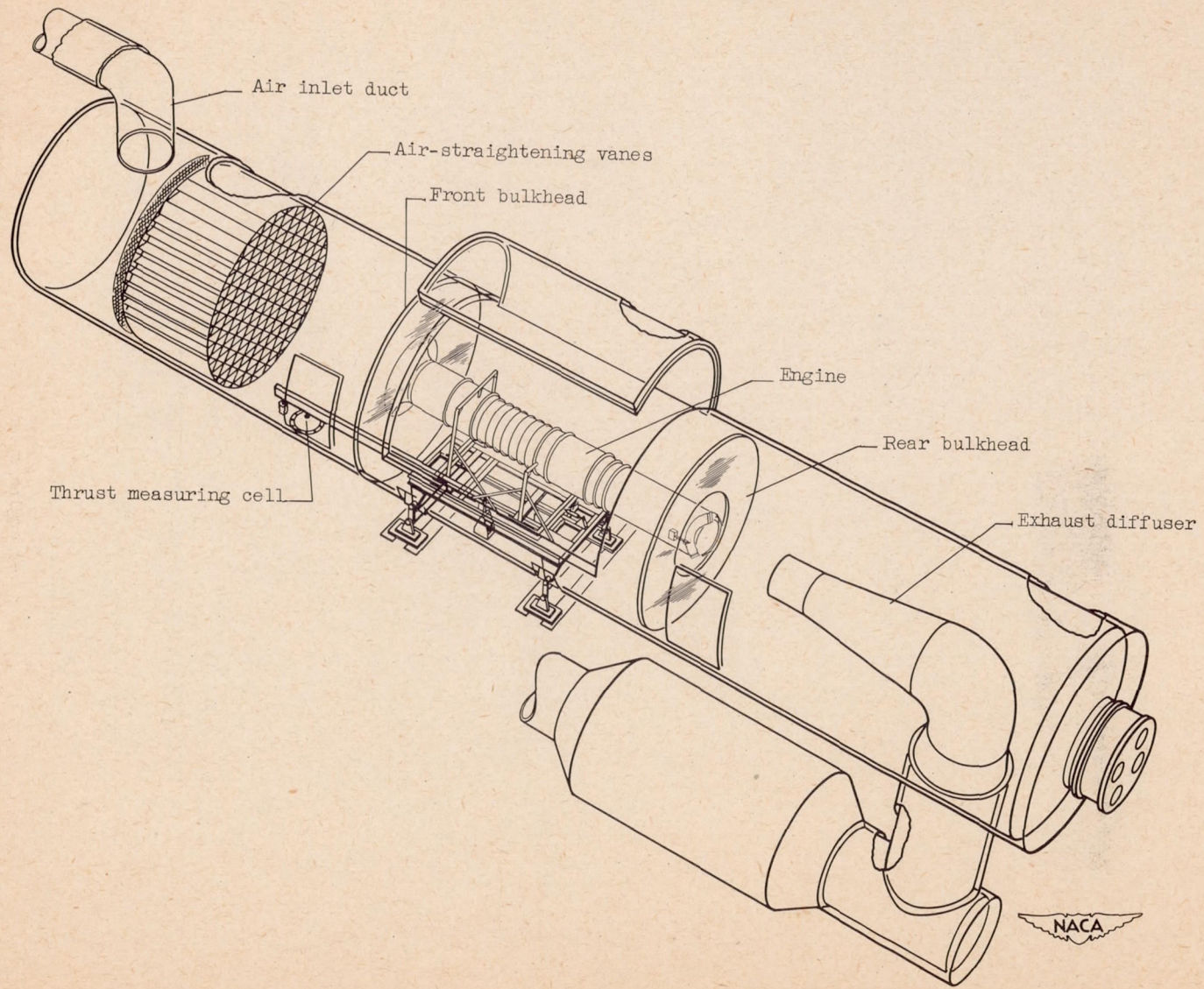


Figure 3. - Altitude chamber with J34-WE-22 turbojet engine installed in test section.

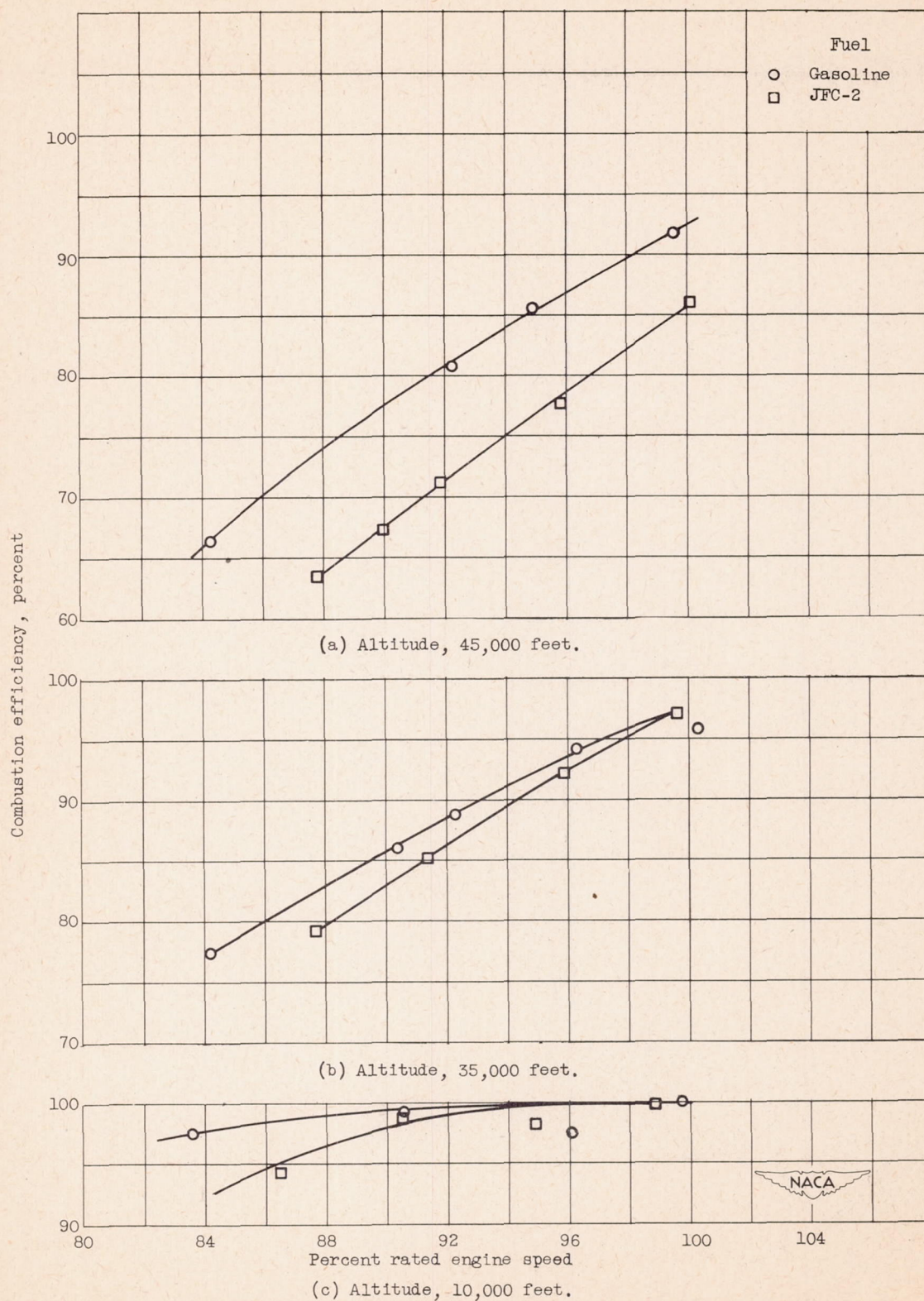
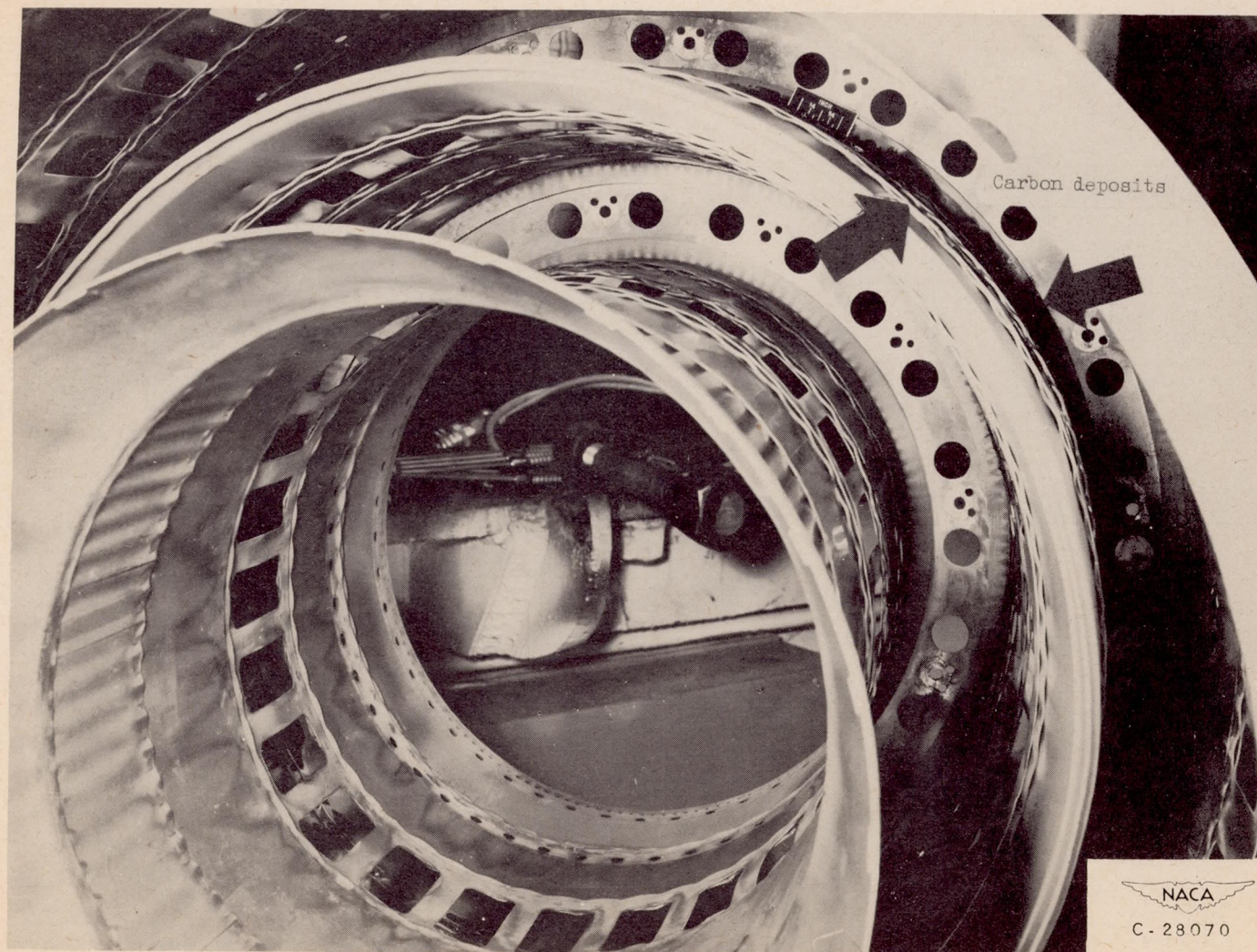


Figure 4. - Effect of engine speed on combustion efficiency of J34 turbojet engine operating with gasoline and JFC-2 fuel at three altitudes; Flight Mach number, 0.8.

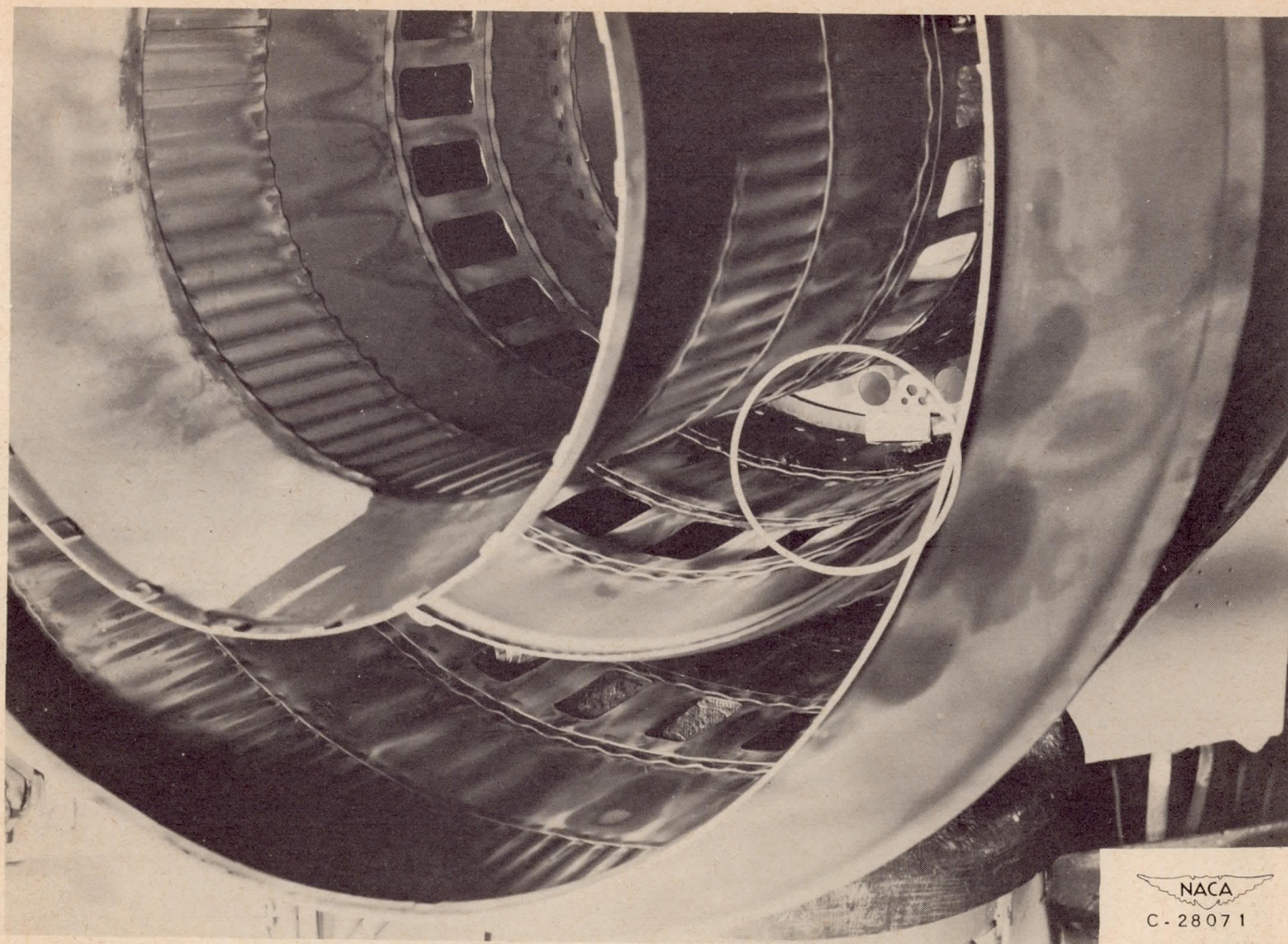


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(a) Upper half of combustor.

Figure 5. - Carbon deposits in J34 combustion chamber after 6 hours and 35 minutes operation with JFC-2 fuel.

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(b) Lower half of combustor.

Figure 5. - Concluded. Carbon deposits in J34 combustion chamber after 6 hours and 35 minutes operation with JFC-2 fuel.

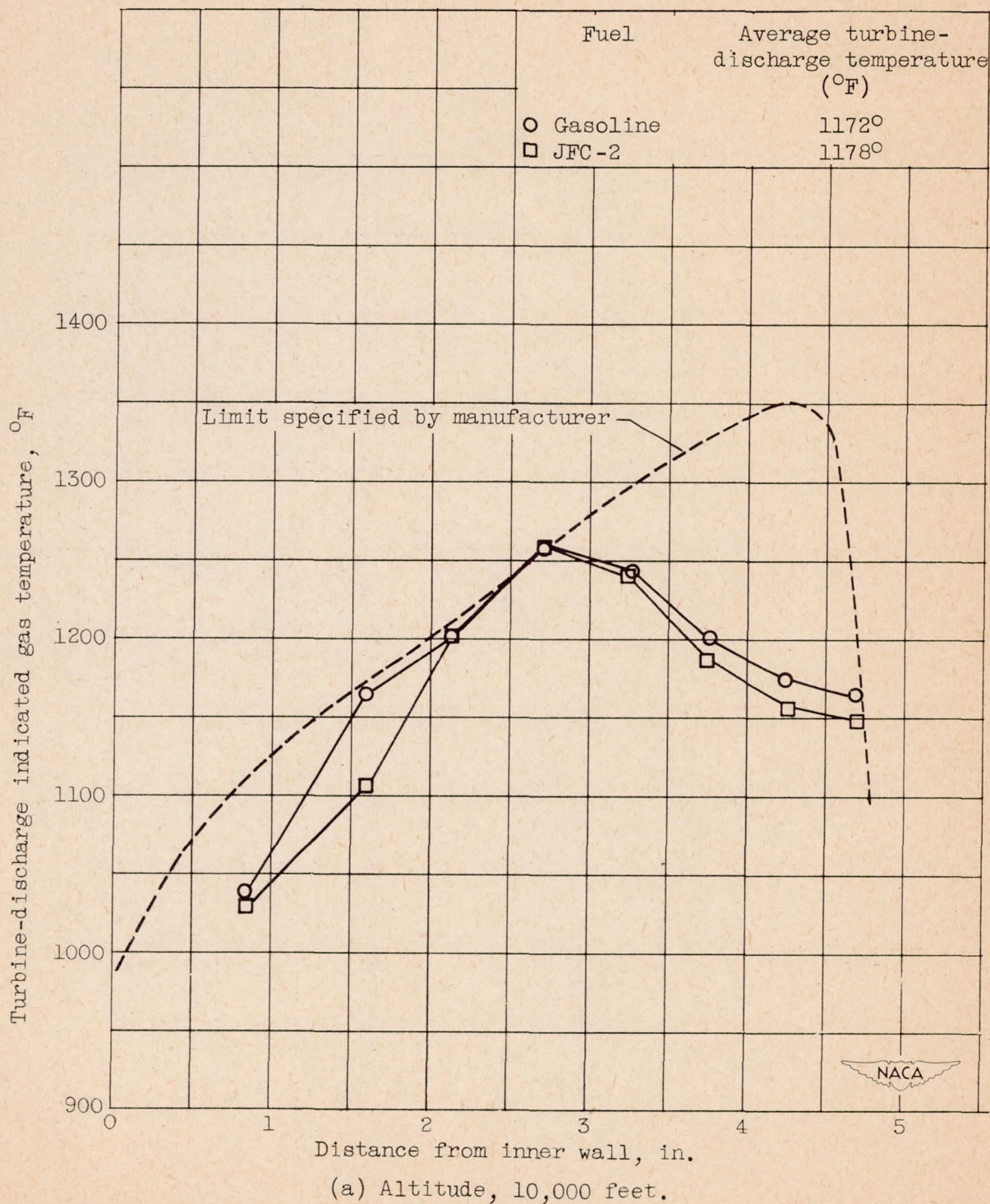
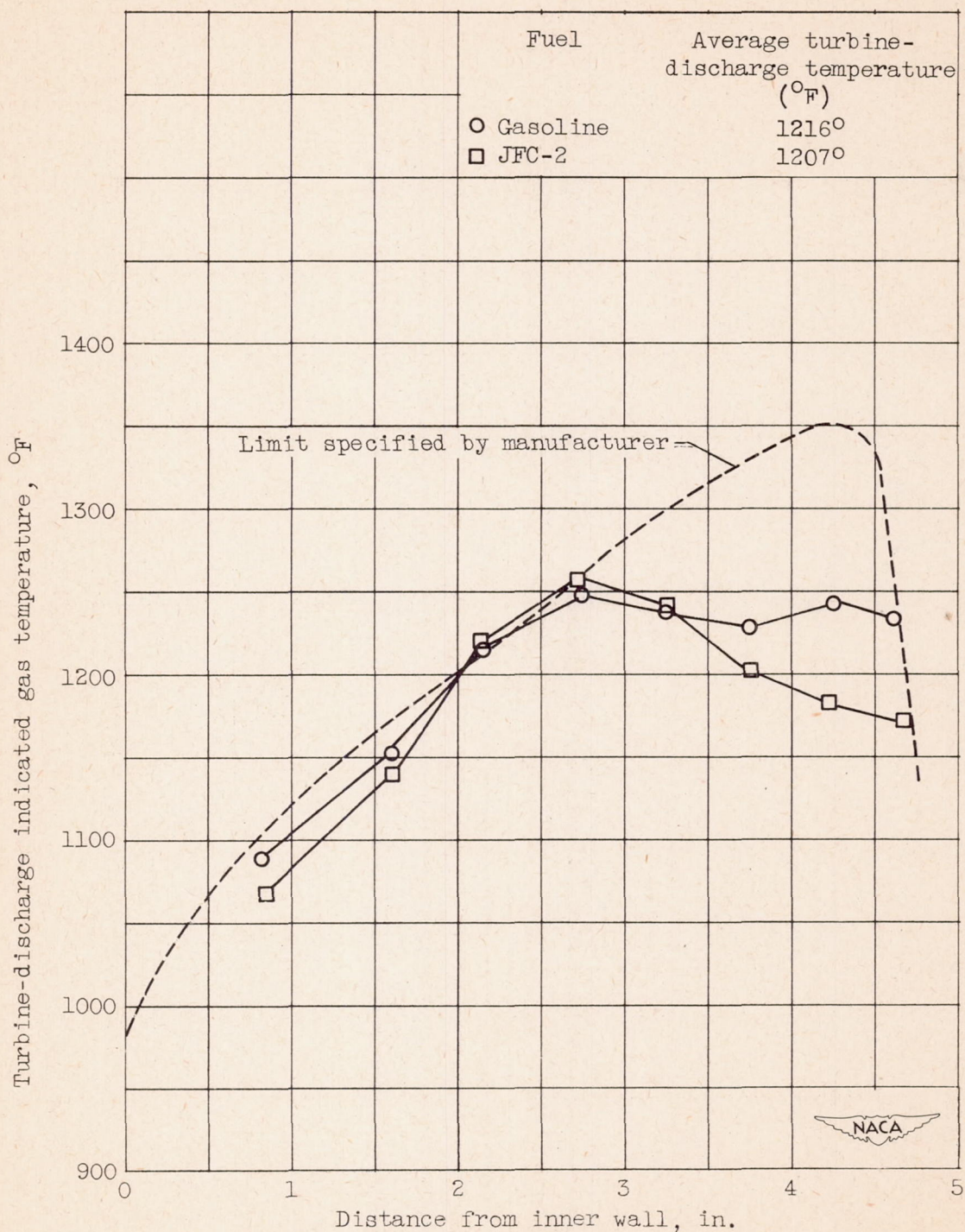


Figure 6. - Radial gas temperature distribution at turbine discharge of J34 turbojet engine operating with gasoline and JFC-2 fuel compared to limit specified by manufacturer. Flight Mach number, 0.8; engine speed, 12,500 rpm.



(b) Altitude, 35,000 feet.

Figure 6. - Continued. Radial gas temperature distribution at turbine discharge of J34 turbojet engine operating with gasoline and JFC-2 fuel compared to limit specified by manufacturer. Flight Mach number, 0.8; engine speed, 12,500 rpm.

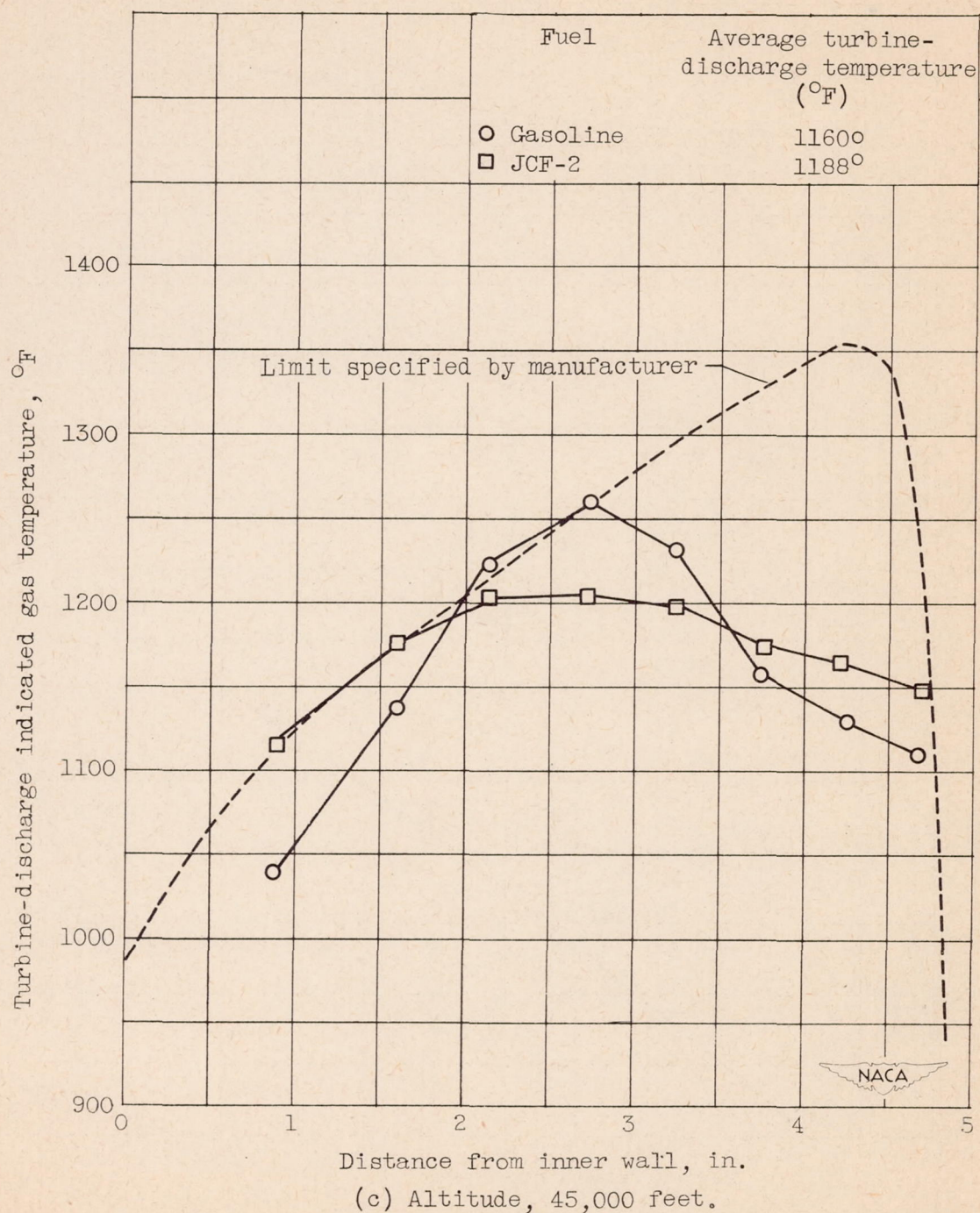


Figure 6. - Concluded. Radial gas temperature distribution at turbine discharge of J34-turbojet engine operating with gasoline and JFC-2 fuel compared to limit specified by manufacturer. Flight Mach number, 0.8; engine speed, 12,500 rpm.

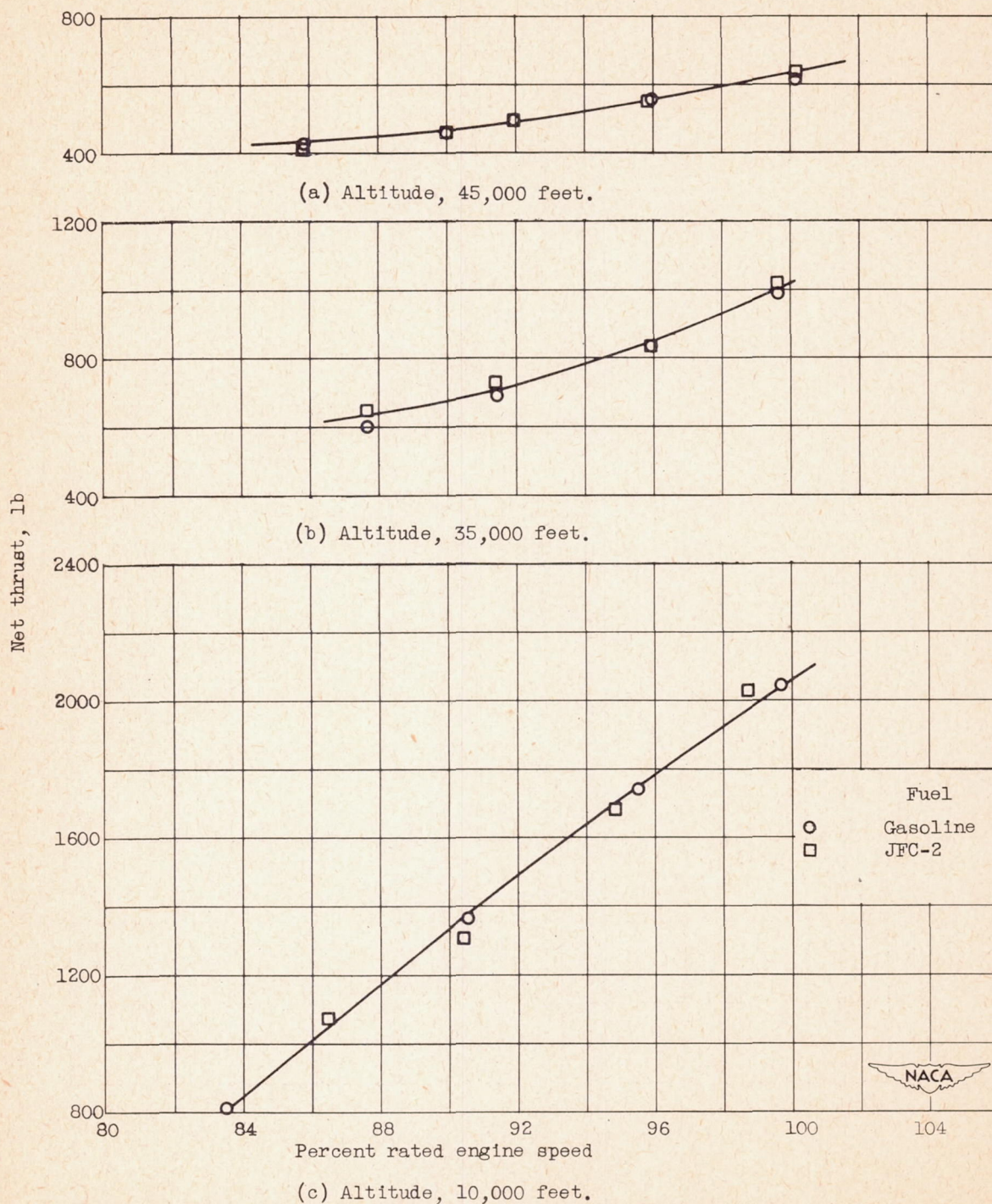
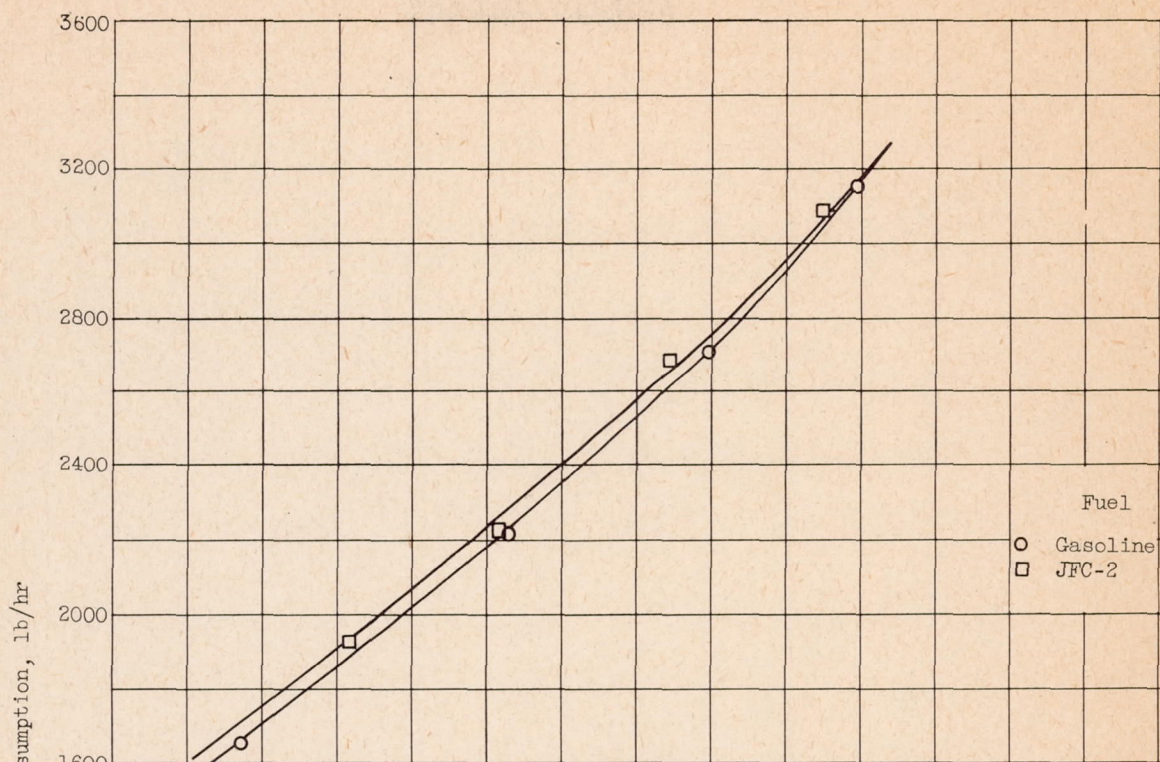
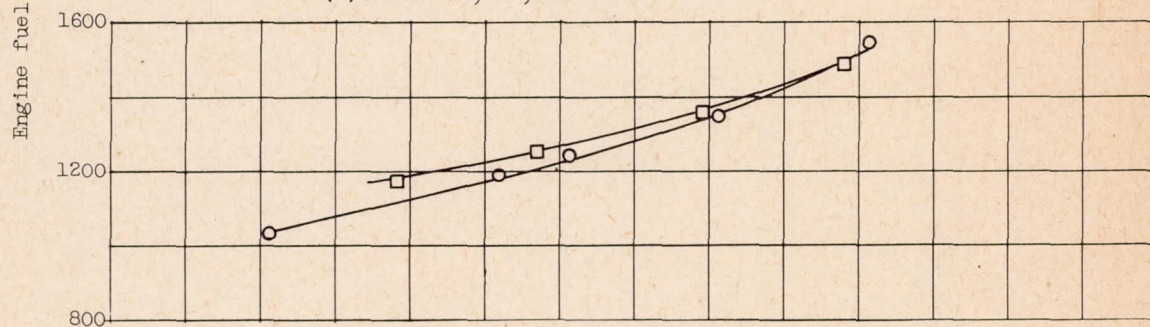


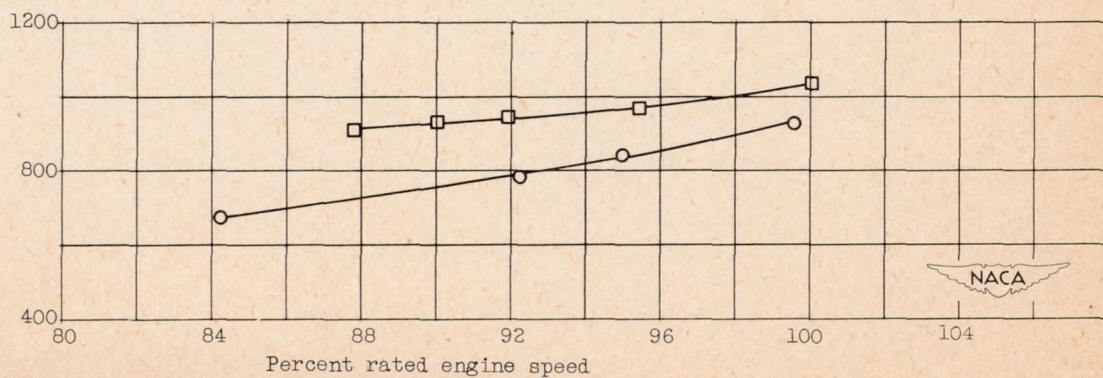
Figure 7. - Net thrust of J34 turbojet engine operating with gasoline and JFC-2 fuel. Flight Mach number, 0.8.



(a) Altitude, 10,000 feet.



(b) Altitude, 35,000 feet.



(c) Altitude, 45,000 feet

Figure 8. - Engine fuel consumption of J34 turbojet engine using gasoline and JFC-2 fuel. Flight Mach number, 0.8.